Physical Review A 2018 vol.97 N6

Maximum reflectance and transmittance of films coated with gapped graphene in the context of the Dirac model

Klimchitskaya G., Mostepanenko V.
Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

© 2018 American Physical Society. The analytic expressions for the maximum and minimum reflectances of optical films coated with gapped graphene are derived in the application region of the Dirac model taking into account multiple reflections. The respective film thicknesses are also found. In so doing the film material is described by the frequency-dependent index of refraction and graphene by the polarization tensor defined along the real frequency axis. The developed formalism is illustrated by an example of the graphene-coated film made of amorphous silica. Numerical computations of the maximum and minimum reflectances and respective film thicknesses are performed at room temperature in two frequency regions belonging to the near-infrared and far-infrared domains. It is shown that in the far-infrared domain the graphene coating has a profound effect on the values of maximum reflectance and respective film thickness leading to a relative increase in their values by up to 65% and 50%, respectively. The maximum transmittance of a graphene-coated film of appropriately chosen thickness is shown to exceed 90%. Possible applications of the obtained results are discussed.

http://dx.doi.org/10.1103/PhysRevA.97.063817

References

[1] M. I. Katsnelson, Graphene: Carbon in Two Dimensions (Cambridge University Press, Cambridge, UK, 2012).

[2] Physics of Graphene, edited by H. Aoki and M. S. Dresselhaus (Springer, Cham, 2014).

[3] A. H. Castro Neto, F. Guinea, N. M. R. Peres, K. S. Novoselov, and A. K. Geim, The electronic properties of graphene, Rev. Mod. Phys. 81, 109 (2009). RMPHAT 0034-6861 10.1103/RevModPhys.81.109

[4] N. M. R. Peres, The transport properties of graphene: An introduction, Rev. Mod. Phys. 82, 2673 (2010). RMPHAT 0034-6861 10.1103/RevModPhys.82.2673

[5] S. Das Sarma, S. Adam, E. H. Hwang, and E. Rossi, Electronic transport in two-dimensional graphene, Rev. Mod. Phys. 83, 407 (2011). RMPHAT 0034-6861 10.1103/RevModPhys.83.407

[6] D. N. Basov, M. M. Fogler, A. Lanzara, F. Wang, and Y. Zhang, Colloquim: Graphene spectroscopy, Rev. Mod. Phys. 86, 959 (2014). RMPHAT 0034-6861 10.1103/RevModPhys.86.959

[7] T. Stauber, N. M. R. Peres, and A. K. Geim, Optical conductivity of graphene in the visible region of the spectrum, Phys. Rev. B 78, 085432 (2008). PRBMDO 1098-0121 10.1103/PhysRevB.78.085432

[8] V. P. Gusynin, S. G. Sharapov, and J. P. Carbotte, Anomalous Absorption Line in the Magneto-Optical Response of Graphene, Phys. Rev. Lett. 98, 157402 (2007). PRLTAO 0031-9007 10.1103/PhysRevLett.98.157402

[9] L. A. Falkovsky and S. S. Pershoguba, Optical far-infrared properties of a graphene monolayer and multilayer, Phys. Rev. B 76, 153410 (2007). PRBMDO 1098-0121 10.1103/PhysRevB.76.153410

[10] M. Auslender and M. I. Katsnelson, Generalized kinetic equations for charge carriers in graphene, Phys. Rev. B 76, 235425 (2007). PRBMDO 1098-0121 10.1103/PhysRevB.76.235425

[11] L. A. Falkovsky, Optical properties of graphene, J. Phys.: Conf. Ser. 129, 012004 (2008). 1742-6596 10.1088/1742-6596/129/1/012004

[12] T. G. Pedersen, A.-P. Jauho, and K. Pedersen, Optical response and excitons in gapped graphene, Phys. Rev. B 79, 113406 (2009). PRBMDO 1098-0121 10.1103/PhysRevB.79.113406

[13] P. K. Pyatkovsky, Dynamical polarization, screening, and plasmons in gapped graphene, J. Phys.: Condens. Matter 21, 025506 (2009). JCOMEL 0953-8984 10.1088/0953-8984/21/2/025506

[14] A. Scholz and J. Schliemann, Dynamical current-current susceptibility of gapped graphene, Phys. Rev. B 83, 235409 (2011). PRBMDO 1098-0121 10.1103/PhysRevB.83.235409

[15] C. A. Dartora and G. G. Cabrera, (Equation presented) gauge invariance leading to charge and spin conductivity of Dirac fermions in graphene, Phys. Rev. B 87, 165416 (2013). PRBMDO 1098-0121 10.1103/PhysRevB.87.165416

[16] M. Merano, Fresnel coefficients of a two-dimensional atomic crystal, Phys. Rev. A 93, 013832 (2016). PRAHC3 2469-9926 10.1103/PhysRevA.93.013832

[17] D. Drosdoff and L. M. Woods, Casimir forces and graphene sheets, Phys. Rev. B 82, 155459 (2010). PRBMDO 1098-0121 10.1103/PhysRevB.82.155459

[18] D. Drosdoff and L. M. Woods, Casimir interaction between graphene sheets and metamaterials, Phys. Rev. A 84, 062501 (2011). PLRAAN 1050-2947 10.1103/PhysRevA.84.062501

[19] B. E. Sernelius, Retarded interactions in graphene systems, Phys. Rev. B 85, 195427 (2012). PRBMDO 1098-0121 10.1103/PhysRevB.85.195427

[20] A. D. Phan, L. M. Woods, D. Drosdoff, I. V. Bondarev, and N. A. Viet, Temperature dependent graphene suspension due to thermal Casimir interaction, Appl. Phys. Lett. 101, 113118 (2012). APPLAB 0003-6951 10.1063/1.4752745

[21] M. Bordag, I. V. Fialkovsky, D. M. Gitman, and D. V. Vassilevich, Casimir interaction between a perfect conductor and graphene described by the Dirac model, Phys. Rev. B 80, 245406 (2009). PRBMDO 1098-0121 10.1103/PhysRevB.80.245406

[22] I. V. Fialkovsky, V. N. Marachevsky, and D. V. Vassilevich, Finiteerature Casimir effect for graphene, Phys. Rev. B 84, 035446 (2011). PRBMDO 1098-0121 10.1103/PhysRevB.84.035446

[23] M. Bordag, G. L. Klimchitskaya, V. M. Mostepanenko, and V. M. Petrov, Quantum field theoretical description for the reflectivity of graphene, Phys. Rev. D 91, 045037 (2015) PRVDAQ 1550-7998 10.1103/PhysRevD.91.045037;

[24] M. Bordag, G. L. Klimchitskaya, V. M. Mostepanenko, and V. M. Petrov, Phys. Rev. D 93, 089907 (E) (2016). 2470-0010 10.1103/PhysRevD.93.089907

[25] M. Bordag, I. Fialkovskiy, and D. Vassilevich, Enhanced Casimir effect for doped graphene, Phys. Rev. B 93, 075414 (2016) PRBHB7 2469-9950 10.1103/PhysRevB.93.075414;

[26] M. Bordag, I. Fialkovskiy, and D. Vassilevich, Phys. Rev. B 95, 119905 (E) (2017). PRBHB7 2469-9950 10.1103/PhysRevB.95.119905

[27] G. L. Klimchitskaya and V. M. Mostepanenko, Conductivity of pure graphene: Theoretical approach using the polarization tensor, Phys. Rev. B 93, 245419 (2016). PRBHB7 2469-9950 10.1103/PhysRevB.93.245419

[28] G. L. Klimchitskaya and V. M. Mostepanenko, Quantum electrodynamic approach to the conductivity of gapped graphene, Phys. Rev. B 94, 195405 (2016). PRBHB7 2469-9950 10.1103/PhysRevB.94.195405

[29] G. L. Klimchitskaya, V. M. Mostepanenko, and V. M. Petrov, Conductivity of graphene in the framework of Dirac model: Interplay between nonzero mass gap and chemical potential, Phys. Rev. B 96, 235432 (2017). PRBHB7 2469-9950 10.1103/PhysRevB.96.235432

[30] G. L. Klimchitskaya, C. C. Korikov, and V. M. Petrov, Theory of reflectivity properties of graphene-coated material plates, Phys. Rev. B 92, 125419 (2015) PRBMDO 1098-0121 10.1103/PhysRevB.92.125419;

[31] G. L. Klimchitskaya, C. C. Korikov, and V. M. Petrov, Phys. Rev. B 93, 159906 (E) (2016). PRBHB7 2469-9950 10.1103/PhysRevB.93.159906

[32] G. L. Klimchitskaya and V. M. Mostepanenko, Reflectivity properties of graphene with nonzero mass-gap parameter, Phys. Rev. A 93, 052106 (2016). PRAHC3 2469-9926 10.1103/PhysRevA.93.052106

[33] G. L. Klimchitskaya and V. M. Mostepanenko, Optical properties of dielectric plates coated with gapped graphene, Phys. Rev. B 95, 035425 (2017). PRBHB7 2469-9950 10.1103/PhysRevB.95.035425

[34] M. Bordag, G. L. Klimchitskaya, and V. M. Mostepanenko, Thermal Casimir effect in the interaction of graphene with dielectrics and metals, Phys. Rev. B 86, 165429 (2012). PRBMDO 1098-0121 10.1103/PhysRevB.86.165429

[35] M. Chaichian, G. L. Klimchitskaya, V. M. Mostepanenko, and A. Tureanu, Thermal Casimir-Polder interaction of different atoms with graphene, Phys. Rev. A 86, 012515 (2012). PLRAAN 1050-2947 10.1103/PhysRevA.86.012515

[36] G. L. Klimchitskaya and V. M. Mostepanenko, Van der Waals and Casimir interactions between two graphene sheets, Phys. Rev. B 87, 075439 (2013). PRBMDO 1098-0121 10.1103/PhysRevB.87.075439

[37] K. Kaur, J. Kaur, B. Arora, and B. K. Sahoo, Emending thermal dispersion interaction of Li, Na, K and Rb alkali-metal atoms with graphene in the Dirac model, Phys. Rev. B 90, 245405 (2014). PRBMDO 1098-0121 10.1103/PhysRevB.90.245405

[38] G. L. Klimchitskaya, V. M. Mostepanenko, and Bo E. Sernelius, Two approaches for describing the Casimir interaction with graphene: density-density correlation function versus polarization tensor, Phys. Rev. B 89, 125407 (2014). PRBMDO 1098-0121 10.1103/PhysRevB.89.125407

[39] G. L. Klimchitskaya and V. M. Mostepanenko, Origin of large thermal effect in the Casimir interaction between two graphene sheets, Phys. Rev. B 91, 174501 (2015). PRBMDO 1098-0121 10.1103/PhysRevB.91.174501

[40] V. B. Bezerra, G. L. Klimchitskaya, V. M. Mostepanenko, and C. Romero, Nernst heat theorem for the thermal Casimir interaction between two graphene sheets, Phys. Rev. A 94, 042501 (2016). PRAHC3 2469-9926 10.1103/PhysRevA.94.042501

[41] G. Bimonte, G. L. Klimchitskaya, and V. M. Mostepanenko, How to observe the giant thermal effect in the Casimir force for graphene systems, Phys. Rev. A 96, 012517 (2017). PRAHC3 2469-9926 10.1103/PhysRevA.96.012517

[42] C. Henkel, G. L. Klimchitskaya, and V. M. Mostepanenko, Influence of chemical potential on the Casimir-Polder interaction between an atom and gapped graphene or graphene-coated substrate, Phys. Rev. A 97, 032504 (2018). PRAHC3 2469-9926 10.1103/PhysRevA.97.032504

[43] A. A. Banishev, H. Wen, J. Xu, R. K. Kawakami, G. L. Klimchitskaya, V. M. Mostepanenko, and U. Mohideen, Measuring the Casimir force gradient from graphene on a (Equation presented) substrate, Phys. Rev. B 87, 205433 (2013). PRBMDO 1098-0121 10.1103/PhysRevB.87.205433

[44] G. L. Klimchitskaya, U. Mohideen, and V. M. Mostepanenko, Theory of the Casimir interaction for graphene-coated substrates using the polarization tensor and comparison with experiment, Phys. Rev. B 89, 115419 (2014). PRBMDO 1098-0121 10.1103/PhysRevB.89.115419

[45] M. Born and E. Wolf, Pronciples of Optics (Cambridge University Press, Cambridge, UK, 1999).

[46] Handbook of Optical Constants of Solids, edited by E. D. Palik (Academic, New York, 1991), Vol. 2.

[47] K. F. Mak, M. Y. Sfeir, Y. Wu, C. H. Lui, J. A. Misewich, and T. F. Heinz, Measurement of the Optical Conductivity of Graphene, Phys. Rev. Lett. 101, 196405 (2008). PRLTAO 0031-9007 10.1103/PhysRevLett.101.196405

[48] Y. V. Bludov, M. I. Vasilevskiy, and N. M. R. Peres, Mechanism for graphene-based optoelectronic switches by turning surface plasmon-polariton in monolayer graphene, Europhys. Lett. 92, 68001 (2010). EULEEJ 0295-5075 10.1209/0295-5075/92/68001

[49] K. Chung, C.-H. Lee, and G.-C. Yi, Transferable GaN layers grown on ZnO-coated graphene layers for optoelectronic devices, Science 330, 655 (2010). SCIEAS 0036-8075 10.1126/science.1195403

[50] R. K. S. Raman, P. C. Banerjee, D. E. Lobo, Protecting copper from electrochemical degradation by graphene coating, Carbon 50, 4040 (2012). CRBNAH 0008-6223 10.1016/j.carbon.2012.04.048

[51] L. F. Dumée, L. He, Z. Wang, Growth of nano-textured graphene coatings across highly porous stainless steel supports towards corrosion resistant coatings, Carbon 87, 395 (2015). CRBNAH 0008-6223 10.1016/j.carbon.2015.02.042

[52] W. Hong, Y. Xu, G. Lu, C. Li, and G. Shi, Transparent graphene/PEDOT-PSS composite films as counter electrodes of dye-sensitized solar cells, Electrochem. Commun. 10, 1555 (2008). ECCMF9 1388-2481 10.1016/j.elecom.2008.08.007

[53] Springer Handbook of Nanomaterials, edited by R. Vajtai (Springer, Berlin, 2013).

[54] S. Watcharotone, D. A. Dikin, S. Stankovich, Graphene-silica composite thin films as transparent conductors, Nano Lett. 7, 1888 (2007). NALEFD 1530-6984 10.1021/nl070477

[55] T. Kuila, S. Bose, P. Khanra, A. K. Mishra, N. H. Kim, and J. H. Lee, Recent advances in graphebe-based biosensors, Biosens. Bioelectron. 29, 4637 (2011). BBIOE4 0956-5663 10.1016/j.bios.2011.05.039